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Possible Evidence for the Existence of Strangeness Analog States*

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Evidence supporting the validity of a simple symmetry in hypernuclei, suggested ten years ago is found in recently published data on ${}^{9}_{\Lambda}Be$, ${}^{12}_{\Lambda}C$, and ${}^{16}_{\Lambda}O$.

The suggestion for the existence of strangeness analog resonances (SAR) was made some time ago,[1] and has been discussed repeatedly in the literature.[2] Such a state, or resonance, in a hypernucleus would have the same wave function and symmetry as a (ground) state of a normal nucleus. A Λ replaces one neutron, averaged over all occupied neutron orbits, in the same way as in the isobaric analog resonances[3] (IAR) a proton replaces a neutron in neutron excess orbits. For ${}^{16}O$ such a wave function is shown schematically in Fig. 1.

Although the Λ-N and N-N interactions are different from one another, Λ-nucleus and N-nucleus interactions are both expected to be described by potential wells having the same general shape determined

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by the size of the nucleus. The wells will differ only in depth, the nucleon potential is deeper than the Λ well. The energy required to transform a nucleon into a Λ in the same orbit would be approximately equal to the difference in the well depths, and should not depend very much on the individual orbits. The different components in the SAR state thus all have nearly the same single-particle excitation energies.

More recently it has been suggested[4] that the Λ-nucleus and N-nucleus interactions cannot be described in terms of simple local wells, and that the energy required to transform an s-shell nucleon into a Λ might be considerably greater than that required for a p-shell nucleon. In this case the SAR state in p-shell nuclei would split into two states having a nucleon hole and a Λ in the s-shell and p-shell, respectively. However, there have been no experimental measurements of the energy required to transform s- and p-shell nucleons into Λ's, and therefore no conclusive tests of this question. This is, of course, relevant to whether the SAR configuration is confined to a single well-defined resonance or is split or smeared over a wide energy interval. The estimates of energies required to transform nucleons into Λ's have been computed indirectly from other measured and estimated parameters, e.g., single-particle energies from (e,e'p) or (p,2p) experiments (where rearrangement energies are never completely understood) and binding energies of the ground states of hypernuclei. The purpose of this note is to point out that data now exist to give a direct experimental test of the SAR hypothesis.

The results in $^{9}_{\Lambda}$Be, $^{12}_{\Lambda}$C, and $^{16}_{\Lambda}$O are, in fact, consistent with the the original suggestion of a simple analog resonance.

The strangeness-exchange (K^-,π^-) reaction was studied by Brückner et al.[5] under conditions of near-zero momentum transfer on ^{9}Be, ^{12}C and ^{16}O. This reaction should populate the SAR configuration selectively over all other possible hypernuclear configurations, just as the (p,n) reaction selectively populates the IAR. Brückner et al., however, have interpreted their data in terms of the strangeness symmetry breaking concepts of Ref. 4, assigning particular particle-hole components to bumps in the spectrum. It is the purpose of this note to point out that the principal structures observed in $^{9}_{\Lambda}$Be, $^{12}_{\Lambda}$C, and $^{16}_{\Lambda}$O are consistent with the original simple suggestion of an analog resonance.

In Ref. 5 the expectation for systematics of SAR energies in the various nuclei is not discussed. In fact, for the concept to be valid a very specific behavior in energy is expected, in close analogy with the isobaric analog states. In the IAR, the effect became apparent when spectra from (p, n) reactions were studied and a prominent final state was seen corresponding to an energy loss or Q-value which was the Coulomb energy: the energy required to replace a neutron by a proton, with the nuclear configuration unchanged.[3] This Q-value changed as $Z/A^{1/3}$ throughout the periodic table, it is nonzero because of the Coulomb interaction that breaks the isospin symmetry.

The strangeness symmetry is broken by the difference in the Λ-nucleus and N-nucleus potential. Unlike the Coulomb energy this difference has its origin in short-range forces and thus should be roughly constant in different nuclei. The relevant energies to compare are then the amount it takes to replace a neutron by a Λ, or the (Λ, n) Q value. The SAR would be expected to occur at about the same, constant Q value throughout the periodic table. In Ref. 5 the (K^-, π^-) spectra are plotted against B_Λ, the binding energy of the Λ, and against the excitation energy of the hypernucleus. The smooth curves drawn through the spectra of Ref. 5 are reproduced in Fig. 2a, plotted as a function of binding energy. In Fig. 2b the same data are replotted as a function of the relevant (Λ, n) Q-value. It is quite clear that in the lower plot the most prominent peak in each spectrum occurs at nearly the same Q-value: about -21 MeV. (The (K^-, π^-) Q value differs from this by a constant, and would be an equally useful energy scale.)

The case of ${}^{9}_{\Lambda}Be$ is slightly different in that ${}^{9}Be$ has isospin $T = 1/2$ and thus its SAR could be broadened, or even split into $T = 0$ and $T = 1$ components; the centroid should be unaffected. The slight difference seen in Fig. 2b between ${}^{9}Be$ on the one hand and ${}^{12}C$ and ${}^{16}O$ on the other may have its origin in such an effect. This broadening is again a function of the difference in the N-N and Λ-N effective interaction and for ${}^{9}Be$ should, at most, be on the order of 2—3 MeV.

We thus wish to point out that the most recent experimental data on excited hypernuclear states seem consistent with the simple symmetry predicted ten years ago. The states are, in fact, seen in the low-momentum-transfer, strangeness-changing reaction, as was the original expectation. Similar experiments on heavier nuclei would be of interest, to see whether a peak occurs at about the same Q-value throughout the periodic table. Clearly much work still remains to be done before the matter will be unambiguous, but the experimental developments of the last few months are encouraging.

We wish to acknowledge discussions with A. Kerman regarding strangeness analog resonances, over the past decade, as well as recently. Thanks are also due to Prof. B. Povh for calling the authors' attention to these recent experimental results.

References

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[1] H. J. Lipkin, Phys. Rev. Letters 14, 18 (1965); H. Feshbach and A. K. Kerman, Preludes in Theoretical Physics, ed. A. deShalit, H. Feshbach, and L. Van Hove, North-Holland, 1966.

[2] A. K. Kerman and H. J. Lipkin, Ann. Phys. (N. Y.) 60, 148 (1971); H. J. Lipkin, Proceedings of the Summer Study Meeting on Nuclear and Hypernuclear Physics with Kaon Beams, Brookhaven National Laboratory, 1973, p. 147.

[3] J. D. Anderson, C. Wong, J. W. McClure, Phys. Rev. 126, 2170 (1962).

[4] N. Auerbach and A. Gal, Phys. Lett. 48B,22 (1974), J. Hüfner, S. Y. Lee, and H. A. Weidenmuller, Phys. Lett. 49B, 409 (1974).

[5] W. Brückner, M. A. Faessler, K. Kilian, U. Lynen, B. Pietrzyk, B. Povh, H. G. Schürlein, H. Schröder, and A. H. Walenka, Phys. Lett. 55B, 107 (1975).

Figure Captions

Fig. 1. Schematic representation of the strangeness analog resonance in ${}^{16}_{\Lambda}O$, corresponding to the ground state of ${}^{16}O$.

Fig. 2. The top figure plots smooth curves drawn through the data in Ref. 5 for π^- spectra (counts/MeV in arbitrary relative units) from low momentum transfer (K^-, π^-) reactions as a function of the binding of the Λ. The lower plot represents the same data plotted against the (Λ, n) Q-value. The rise to the right is from the $K^- \rightarrow 2\pi$ process.

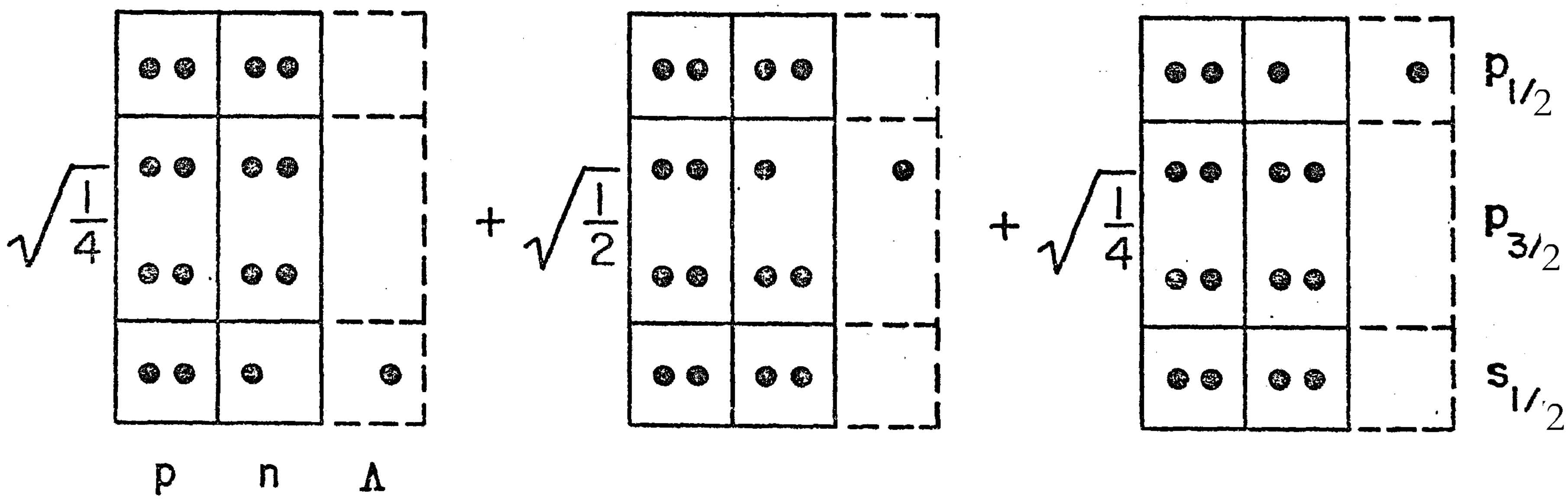

Figure 1

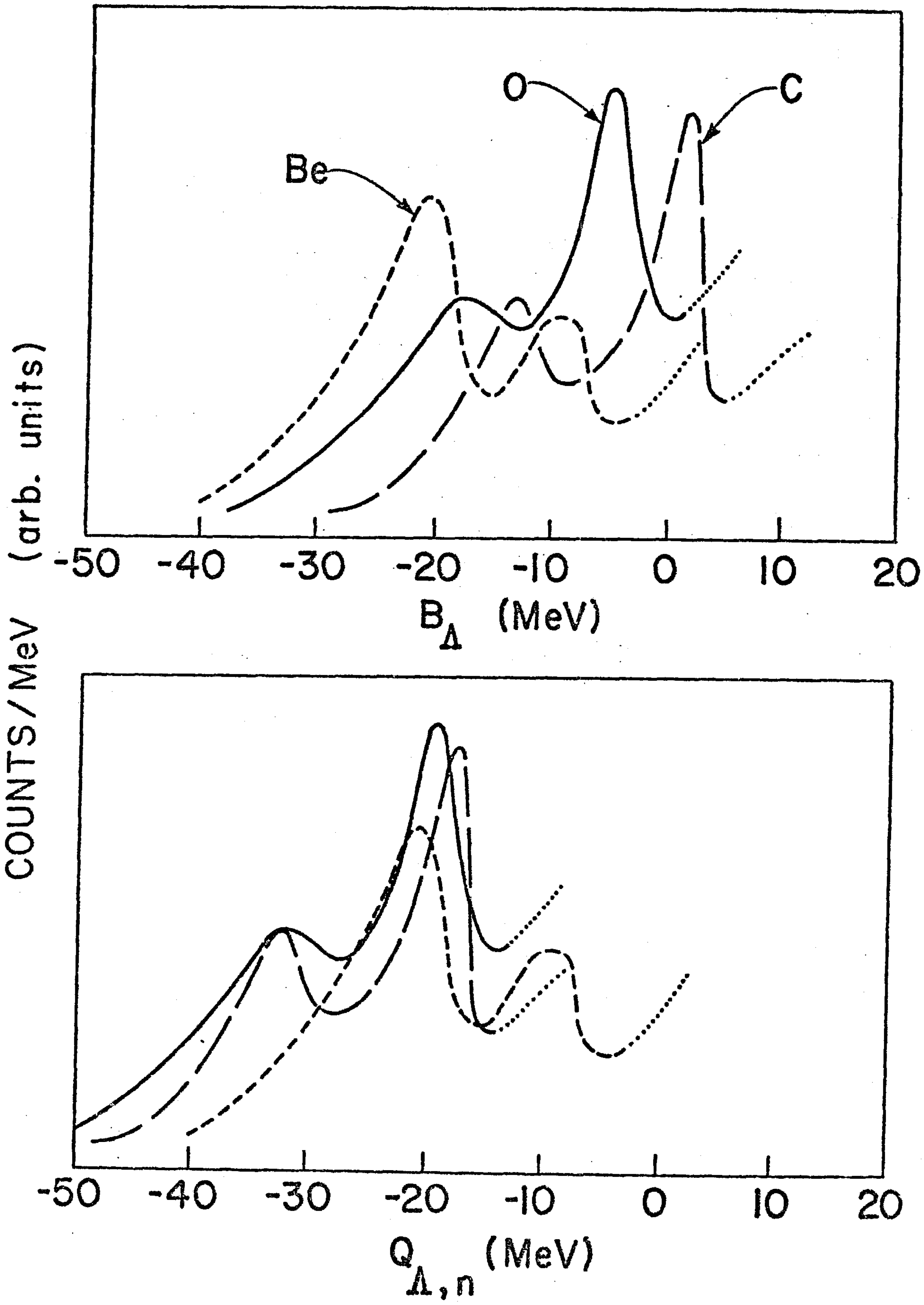
O
C
Be
COUNTS/MeV
(arb. units)
-50
-40
-30
-20
-10
0
10
20
B_Λ (MeV)
$Q_{\Lambda,n}$ (MeV)

Figure 2